The armature coils, separately wound and insulated, are pressed into these slots. The scheme of the winding (Y-grouping) is indicated in Fig. 149.

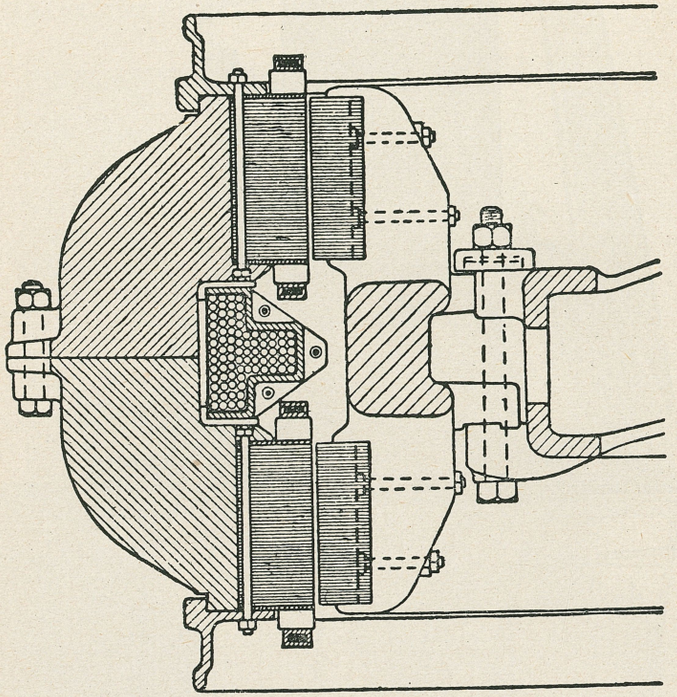

FIG. 148.—DETAILS OF RHEINFELDEN MACHINE.

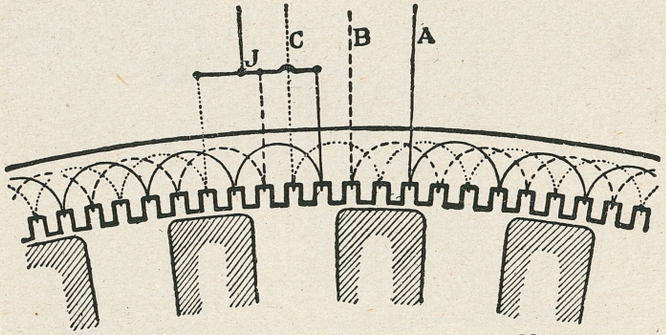

FIG. 149.—WINDING SCHEME OF RHEINFELDEN MACHINE.

ASYNCHRONOUS GENERATORS.

It has been found by several experimenters independently —amongst them Mr. C. E. L. Brown, and the engineers of the General Electric Company, at Schenectady, New York— that the asynchronous induction motors, whether polyphase or monophase, can act as generators provided they are mechanically driven at a slightly higher speed than that of synchronism (see page 216). But it is not possible to work a circuit with only one such machine to be used as a generator —it is not self-exciting. There must be an alternating or polyphase current already supplied to the mains or terminals. It would probably be convenient in those central stations where the load is apt to show very sudden increase, to use one or more asynchronous generators along with other alternators, as the asynchronous generator might be kept turning as a non-loaded motor at a speed just below synchronism until required. On merely quickening up the speed of its engine (without waiting to "synchronise") it will begin to work as a generator, its electromotive impulses synchronising perfectly with those of the circuit, though its speed is not synchronous.

In some experiments made in Sweden[1] by Mr. Danielson in 1892, a three-phase synchronous motor was coupled with a synchronous three-phase generator. The former was then driven as generator, and the latter used as motor, running on a brake. It was found that the asynchronous machine would not generate if the circuit included only resistances (lamps) or resistance with self-induction.

AMERICAN TYPES.

The Westinghouse Company, who own the Tesla patents in America, have equipped their works at Pittsburg with a very perfect system of transmission of power throughout the shops by means of two-phase currents. The generators used for this purpose are illustrated in Fig. 150, which shows a 500 horse-power machine coupled directly to one of the

[1] *Electrical World* (N. Y.), Jan. 1893, p. 44; *Electrical Review*, xxxii. p. 169.

company's enclosed compound engines. The fourteen poles of the field-magnet are of laminated steel built up of punchings riveted together, with the yoke cast solidly around them. The

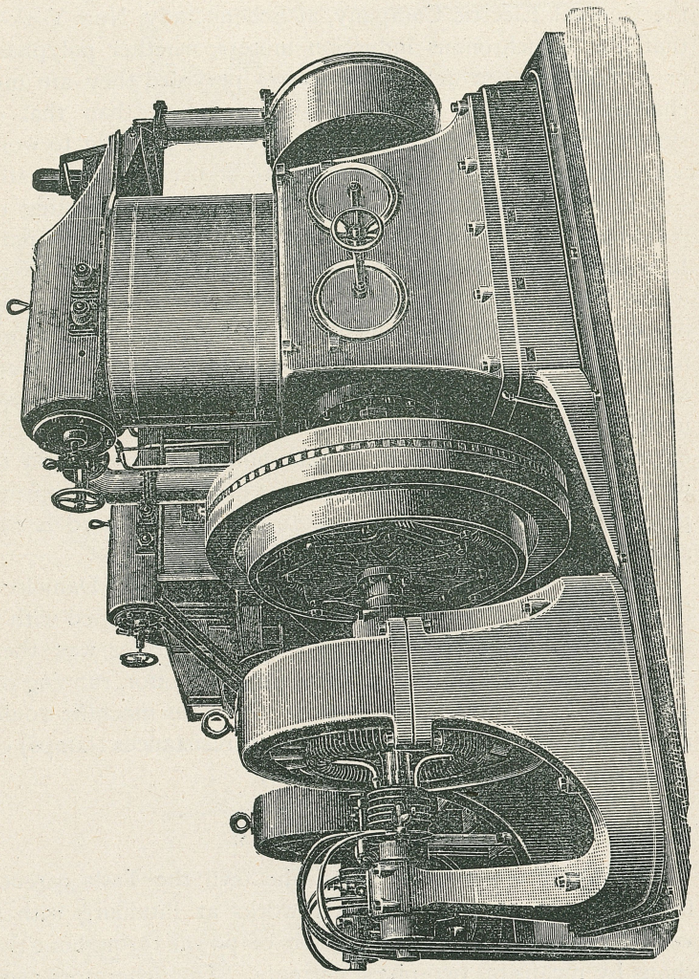

FIG. 150.— WESTINGHOUSE ENGINE AND 500 HORSE-POWER GENERATOR.

exciting coils have but a single circuit, as regulation is secured through a rotatory transformer which supplies the total field current. The general dimensions are 7 feet 10 inches by

8 feet 8 inches and 8 feet 3 inches in height. The armature is built up of slotted stampings mounted on a spider, the whole providing for thorough ventilation during operation. The periphery contains ninety-two slots, in which the bar winding is held in position by strips of rigid insulating material secured by grooves inside the slot, no binding wires being necessary. The armature winding is of the continuous type, a wave-wound drum, like that shown diagrammatically in Fig. 99, save that it is re-entrant, and the four connexions are brought out at points 90 degrees from each other to four slip-rings, where the current is collected by means of copper brushes. These collecting rings separated by insulating collars (shown in Fig. 151), are $5\frac{1}{2}$ inches in diameter with $1\frac{1}{2}$-inch faces. There are four brush-holder arms, two per circuit, which carry two brushes to each arm in order to ensure efficient contact.

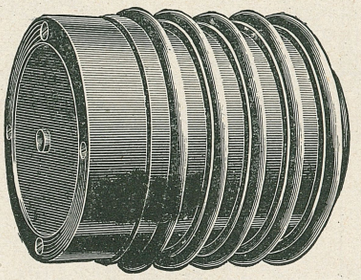

FIG. 151.

The machines run at a speed of 215 revolutions per minute. They generate 400 amperes in each of the two circuits at 240 volts, the frequency being twenty-five per second. These generators are usually run in parallel.

In the last three years the Westinghouse Company has developed other types of polyphase generators and constructed many of large size.[1] The most notable of these are the two-phase machines furnished to the Cataract Company's station at Niagara.

The Niagara installation is the largest example of the now numerous power stations which have been developed in America in recent years, with polyphase plant both for long-distance transmission, for factory-running in the neighbourhood, and for lighting.

[1] For further details, see *Electrical World*, xxxv. p. 745, June 29, 1895; and xxvi. p. 14, July 6, 1895.

In general design the Niagara generators recall the umbrella-pattern of machine, which originated at the Oerlikon Works at the time when Mr. C. E. L. Brown was chief designer there. But the special feature introduced by Professor George Forbes into these machines is the arrangement of the

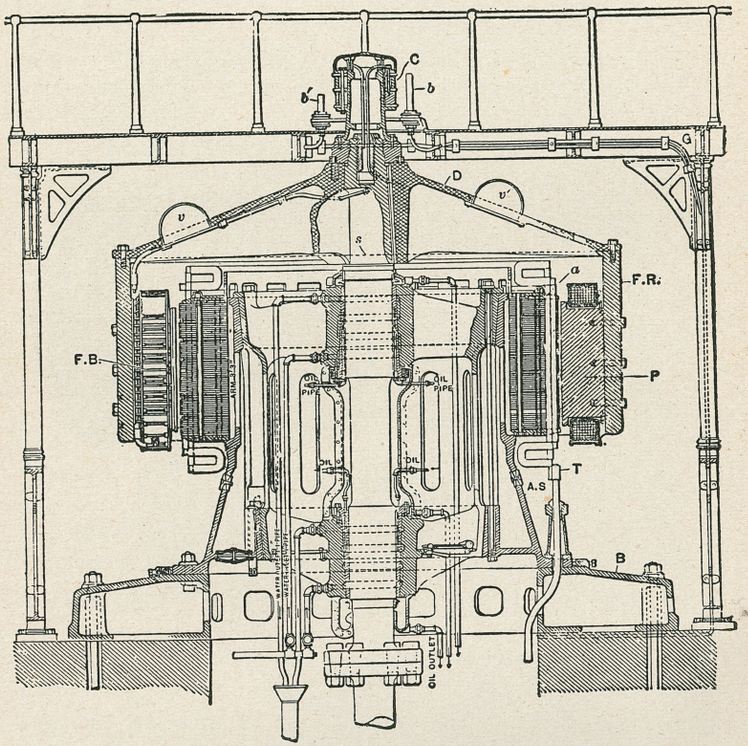

FIG. 152.—SECTIONAL ELEVATION OF NIAGARA 5000 H.P. TWO-PHASE GENERATOR. Scale 1 : 50.

revolving field-magnet as an external steel cylinder having inwardly pointing poles. This form possesses great strength, and great fly-wheel action—a most desirable point in turbine-driven machines. It also has the advantage over those forms in which the revolving poles point outwardly, that the centrifugal forces tending to make the exciting coils and the pole-

cores fly outwardly are largely balanced by the magnetic pull tending inwardly. This feature was preserved throughout the various modifications that the design underwent before it reached its final form. A 5000 horse-power alternator had never before been built. But the best engineering skill in

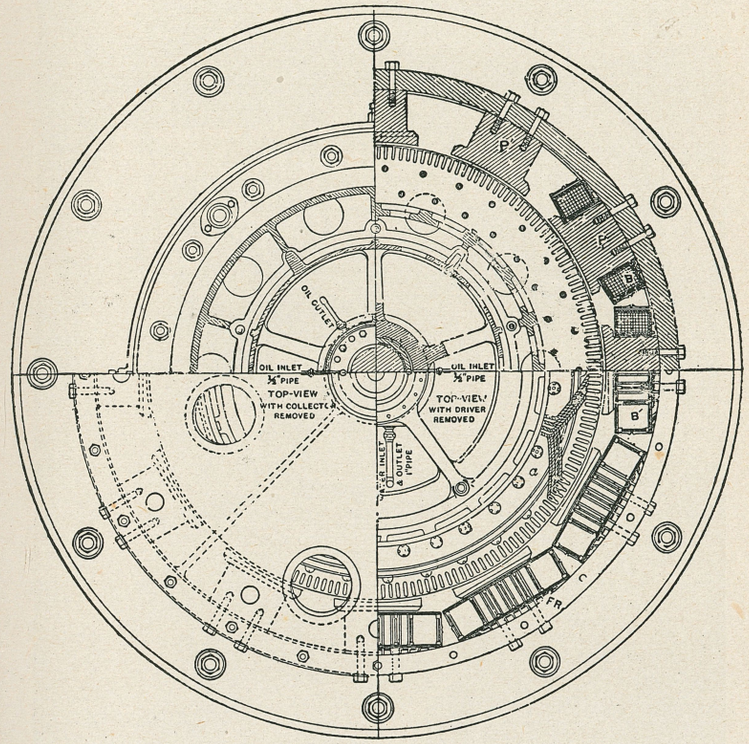

FIG. 153.—PLAN OF NIAGARA 5000 H.P. TWO-PHASE GENERATOR.

Europe and America was brought into requisition ; the criticism of experts was widely solicited ; and the experience and workmanship of the constructors resulted in a wholly successful machine. Six machines, each of 5000 horse-power, formed the first plant.

Figs. 152 and 153 show one of these alternators wound for

2000 volts. The field-magnet consists of a nickel-steel ring, forged without a weld, from the interior periphery of which

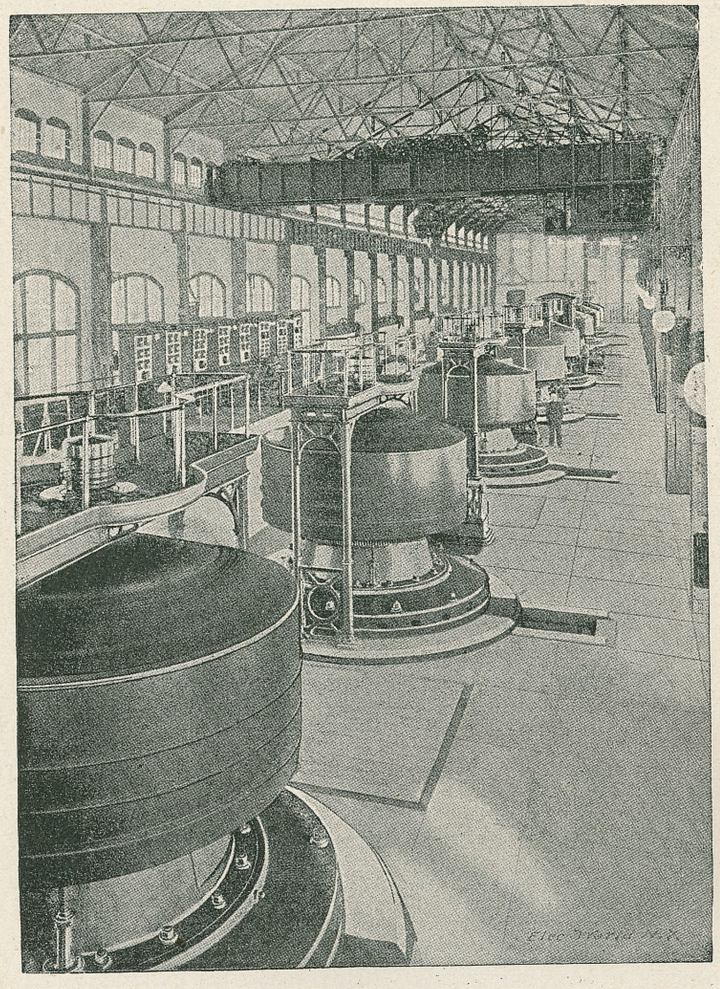

FIG. 154.—THE NIAGARA GENERATORS AT THE CATARACT COMPANY'S WORKS.

project 12 pole-cores. This structure is suspended from an umbrella-shaped frame fixed to the top of the vertical turbine

shaft. The shaft, which is about 180 feet high, passes through a bronze bearing which is supported by five arms projecting inwardly from a cast-iron bearing-ring. The latter is itself fixed adjustably within an outer cylindrical mantle of cast iron standing on an annular foundation, and carries the stationary internal armature. The core of this armature is built up of thin sheet-iron segmented rings (see Fig. 153, page 131). There are 187 slots in the outer face, with two conductors in each slot. Each conductor is $1\frac{11}{32}$ inch by $\frac{7}{16}$ inch in section, with slightly rounded edges. The insulation is of mica. The drawings show the method of connecting up, as also the method of bolting the laminated iron to the cast-iron frame of the armature. The winding consists of two independent non-re-entrant wave-windings distributed regularly around the periphery, there being 374 conductors in all, the machines being two-phase. Around the hub of the bearings are cut grooves (shown in dotted lines) which permit of a water circulation to keep the bearings cool.

The actual voltage at the speed of 250 revolutions per minute is 2250, the output in each of the two currents being 775 amperes. As there are twelve poles, the frequency at this speed is 25 periods per second. The field-magnet windings are supplied with continuous current (derived from a rotatory converter) through two slip-rings fixed on the top of the shaft. Fig. 154 gives an external view of the machines in the power house. The total height is about 13 feet.

The following are some particulars of these generators:—

Output	5300 kilowatts
Revolutions per minute	250
Full load current in one phase	775 amperes
Voltage	2250 volts
Frequency	25 cycles per second
External diameter of revolving field	$139\frac{1}{8}$ inch
,, of stationary armature	103 inch
Number of slots	187
Number of segments per core disk	11
Number of slots per segment	17
Radial depth of segment	$13\frac{1}{4}$ inch
Size of conductors (bare)	$13\frac{1}{2} \times \frac{7}{16}$ inch
Depth of slots	3·186 inch
Width of slots	0·687 inch

Peripheral speed	9000 ft. per min.
Ventilating ducts	6 of 1 inch width
Length of gap	1 inch
Temperature rise on full load	57° C.

More recently the Niagara station has been enlarged by the addition of four very similar machines, also constructed by the Westinghouse Company. These are generally of the same type and size, but with the following modifications. The yoke ring is slightly heavier, having greater moment of inertia. The field-poles are wound with edge-on copper strip 1 inch broad and $\frac{1}{8}$ inch thick, insulated by shellac and mica only, there being four layers around each pole, separated by ventilating ducts from one another, enclosed in a skeleton casting of brass. All turns are in series, having $1\frac{1}{2}$ ohm resistance; the exciting current being 50 amperes at no load, 80 amperes at full load. The pole-cores of cast steel are furnished with extended polar expansions, also cast, reducing the reluctance of the gap. These shoes embrace 70 per cent. of the pole-pitch and are chamfered back about $\frac{1}{3}$ inch. The new armatures have 12 ventilating ducts, each $\frac{1}{2}$ inch wide. The core stampings are of open-hearth steel, 258 mils. thick, clamped together by end-plates, and have 322 slots. Their external diameter is 170 inches. The armature frame of cast iron has vertical channels for a cold-water circulation. The conductors, one per slot, are 2 inches by $\frac{7}{32}$ inch in section, with rounded corners. Their insulation is of mica, several layers being wound around the copper. The gap is $\frac{3}{4}$ inch. The arrangement is depicted in Fig. 155. The end connections are made with two layers of spirals, so as to constitute two independent non-re-entrant wave-windings. The iron losses at full load of 3750 kilowatts, amount to 32·1 kilowatts; the copper loss in armature to 28·4 kilowatts; that in the field-magnet windings 7·4 kilowatts. This gives an efficiency (not including friction losses) of over 98 per cent. The flux-density is about 15 per cent. higher than that in the older machines, and the number of conductors is 322 as against 374. The current density is about 1900 amperes per square inch. The machine when short-circuited, with full-load excitation, gives about twice the full-load current, the armature reaction being fairly high. The machines continue, when on full load, to rise in temperature for about five hours, the limit for a 10 per cent. overload being reached at about 47° C. above

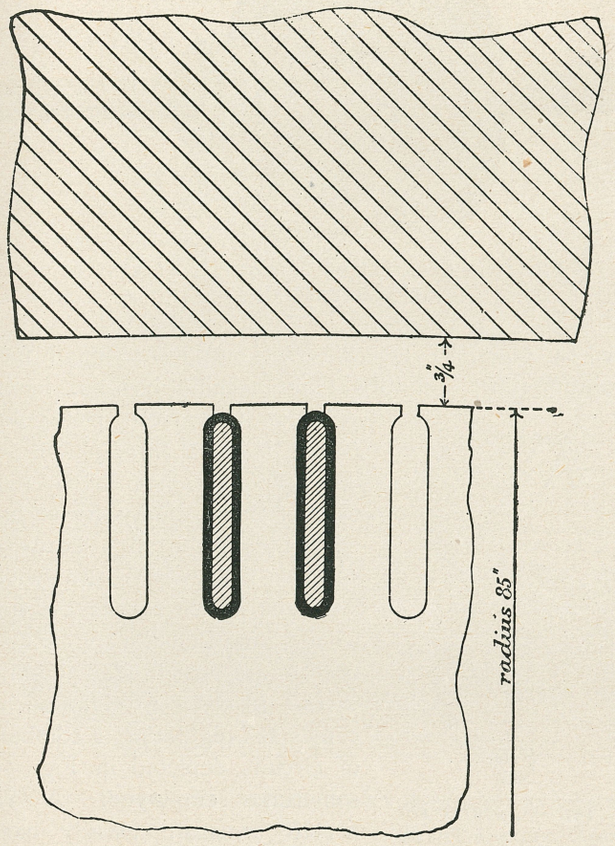

FIG. 155.—DETAILS OF NEW NIAGARA ALTERNATORS.

atmospheric temperature. Further details are given in the *Electrical World* for January 7, 1899.

The great rival American firm, the General Electric Company, of Schenectady, has produced numerous different